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FOR

HOLOGRAPHIC GRATINGS FOR SPECTROGRAPHIC APPLICATIONS: STUDY OF ABERRATIONS

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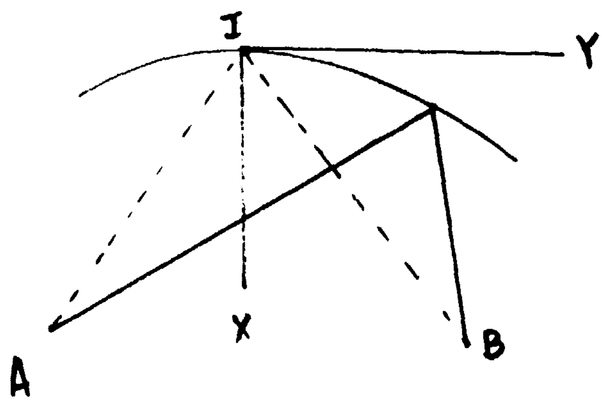
Holographic Gratings For Spectrographic Applications:

Study of Aberrations

The design and fabrication of holographic gratings requires a deep understanding of Fermat's principle. This principle states that the path of a light ray from one point to another is that which requires the least time. Utilizing Fermat's principle, we study the aberrant optical path of an object point A to an image point B (see diagram below).



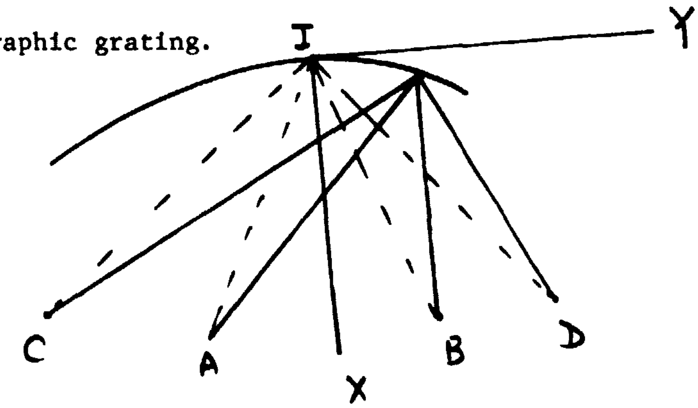
We describe the aberrations (astigmatism, coma, spherical) of the image point B of A by a difference between the optical path AM + MB and a constant that is generally chosen equal to AI + IB; I being the origin of the coordinate system. Then the aberrant optical path is:

$$\Delta = (AM + MB) - (AI + IB).$$

This symbolic equation represents a simplistic geometry for a conventional grating. For a holographic grating, the above equation is written as follows:

$$\Delta = (MA + MB) - (IA + IB) - \frac{K\lambda}{\lambda_0}\left[(MC - MD) - (IC - ID)\right] = 0$$

Where the additional terms are the holographic grating terms. The holographic contribution makes it possible to correct or reduce aberrations such as astigmatism or coma as a function of wavelength. The following diagram shows the use conditions and the recording conditions of a holographic grating.



Where: λ_0 = laser recording wavelength of radiation

C = recording point source

D = second recording point source

λ = is the wavelength at image B of A.

K = is the order at which the holographic grating operates (can be negative or positive).

A = point source under performance or use conditions. At a specific angle α

B = the diffracted image under performance or use conditions at some angle β.

For the past two and a half years we have gained a detailed knowledge of the above brief presentation and have developed computer programs which make it possible to design holographic reflecting diffration gratings useful in spectroscopic instrumentation. The programs are

capable of determining optimum design parameters (γ, δ, groove frequency, K, r_c, r_d) as a function of use parameters (α, β, groove frequency, K, r_a, r_b).

Where: α = angle between the normal to the grating and the recording point C.

δ = angle between the normal to the grating and the recording point D.

r_c = distance from the center of the grating to the recording point source C.

r_d = distance from the center of the grating to the recording point source D.

K = order in which the grating operates.

α = angle of incidence between the normal to the grating and light source A.

β = diffracted image angle as a function of wavelength between the normal to the grating and the image B.

r_a = distance from the center of the grating to the light source A.

r_b = distance from the center of the grating to the diffracted image B.

Four computer programs have been developed to date. The first program determines the optimum recording parameters for correcting astigmatism and coma simultaneously at selected wavelengths for a Rowland circle spectrographic mount. The program shows that solutions are possible for correcting both astigmatism and coma at wavelengths equal to or greater than the recording wavelength. The program then presents a display of the numerical aberrations for both the conventional grating and the holographic grating as a function of wavelength for any angle

of incident radiation. Normally, the display will be for the use parameters for which the holographic grating was designed (α, β, groove frequency, K, r_a, r_b). The use of this program makes it possible to design a spectrograph having the best conditions for aberrations and optimum performance.

A second program was developed for a Rowland circle spectrographic or monochromator mount to determine the optimum racording parameters as a function of use parameters that corrects for astigmatism or coma but not both simultaneously at selected wavelengths below, equal to or greater than the laser recording wavelength. Solutions have been or can be determined for all wavelengths. However, the program shows that there is a trade off because when astigmatism is corrected coma is greater and vice versa. Under certain conditions a happy medium is achieved depending on the use parameters. This program also displays the performance of the holographic grating and conventional grating as a function of wavelength relative to numerical aberrations. This program considers both negative and positive orders of the grating.

The third and fourth programs have been combined because one depends upon the other. These programs determine optimum recording parameters as a function of use parameters for fixed entrance and exit slits relative to a grating rotating about its vertical axis. A literature search shows that Greiner and Shaefer[2] and Namioka[3] have done a considerable amount of work in this area. As a result, the third program was developed to determine the optimum instrumental parameters

(r_a, r_b, α, β, C, groove frequency) relative to a conventional grating. C is the angle between the exit and entrance slits relative to the grating. By coupling the information obtained from this program with the holographic contribution, a fourth program was developed to determine the optimum recording parameters required to design a holographic grating. For a specified wavelength range, the combined program for negative orders only, will determine: the optimum use instrumental parameters, and the optimum recording parameters for either minimizing astigmatism or coma over a selected wavelength range or it will correct astigmatism or coma at selected wavelengths within the desired wavelength range. Then with this information the computer program displays the performance of the conventional and holographic gratings relative to the aberrations numerically.

The forgoing is a brief presentation of the work performed to date. Detailed documentation of the computer programs are being prepared and will be available in the very near future.

For future work, a program will be developed with the grating operating in the positive order for an instrument utilizing a rotating grating and fixed entrance and exit slits. We will also develop computer programs for instruments using toroid type gratings because they have the potential of improving the optical performance at grazing angles of incidence.

REFERENCES

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